EXAMPLES OF RADIATION WASTEWATER TREATMENT IMPLEMENTED IN VARIOUS COUNTRIES

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ABSTRACT

With the increase in population in many of the big cities and the growing industrialization in many countries, the pollution load on the environment is increasing. Of particular concern is the waste containing pathogenic bacteria, parasites and viruses. Reduction of non-organic and organic pollutants as well as destruction of bacterial flora became very important and urgent practical issue. For this reason, research in various countries has been exploring new effective and economical techniques for wastewater treatment. One of the techniques that have been recently implemented in several countries is the utilization of ionizing radiation for wastewater and industrial wastes treatment. High power accelerators are used as well-controlled sources for radiation treatment of wastewater. The radiation treatment of sewage sludge offers an efficient, simple and reliable method to produce pathogen-free sludge, which can be further upgraded to produce bio-fertilizers. Examples of electron beam systems used for wastewater treatment at some countries are presented.

I. INTRODUCTION

Rapid population growth and increased industrial development have led to the generation of large quantities of polluted industrial and municipal wastewaters. The recognition that these polluted waters may pose a serious threat to humans has lead researchers to seek effective technologies for their treatment. In addition to the conventional wastewater treatment techniques, research in several countries over the world, has been exploring new effective and economical techniques for wastewater treatment. One of the techniques implemented recently is the utilization of ionizing radiation for wastewater and industrial wastes treatment, reduction of sewage sludge sanitary contamination and solid agriculture wastes transformation.

II. RADIATION TREATMENT OF WASTEWATER

Radiation treatment aims at the degradation of pollutants at a rate faster than conventional treatment techniques. Water is not normally reactive, but when it is subjected to ionizing radiation, it produces highly reactive species. The ionizing radiation can be produced by the use of a gamma radiation source (such as ^{60}C or ^{137}Cs) or the use of an accelerator that generates a high-energy electron beam. As the high-energy electrons impact flowing polluted water, the electrons slow down, lose energy, and react with the water to produce the three reactive species (hydrated electrons, hydroxyl radicals and H atoms) responsible for organic compound destruction. These short-lived radicals drive both oxidation and reduction reactions at the same time. High energy electron beam irradiation is the only process that is capable of forming both highly oxidizing and highly reducing reactive species in aqueous solutions at the same time and in relatively the same concentrations. Furthermore, no other advanced oxidation process has the capability of generating as high an overall free radical yield per unit energy input as high energy electron beam treatment. Radiation processing offers the following advantages:

- Strong reducing and oxidizing agents.
- Process controllability.
- Compatibility with conventional methods.

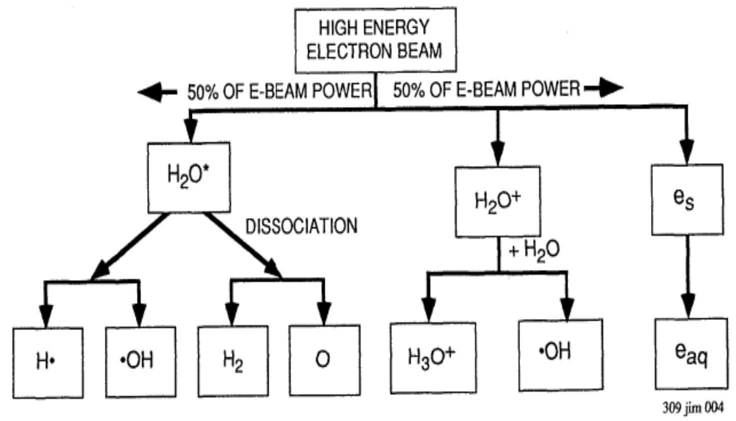
III. WATER RADIOLYSIS

High energy irradiation produces instantaneous radiolytic transformation through energy transfer from high energy photons or accelerated electrons to the orbital electrons of water molecules. Absorbed energy disturbs the electron system of the molecule resulting in the breakage of interatomic bonds. When a high energy electron beam irradiates water, approximately 50% of the electron beam power goes into ionizing the water molecules forming H_2O^+. The other 50% of beam power results in excited water molecules, H_2O, [1].

The primary products of the radiolysis are the hydrated electrons (**e^-_{eq}**), H atoms, OH, and HO_2 radicals, H_2O_2 and H_2 as in the following reaction:

$$H_2O \xrightarrow{\text{Radiation}} e^-_{eq}, H, H_2O, H_2O_2, H_2 \quad (1)$$

These primary reactions and subsequent secondary reactions products are shown in Fig. 1, below. The G value is defined as the number of species produced for every 100 eV of electron beam energy absorbed.



G Values of Various Ions and Radicals

Product	H•	•OH	H_2	H_2O_2	H_3O^+	OH^-	e_{aq}
G Value	0.6	2.8	0.45	0.7	3.1	0.4	2.7

Fig. 1 Various ions and radicals formed by electron beam irradiation of water, [1].

IV. RADIATION DISINFECTATION OF SEWAGE SLUDGE

Irradiation of sewage sludge has been investigated in several countries in the last few years, to provide solution to the environmental problem related to its disposal and the important role it can play in providing organic matter and nutrients to the soil. This can be helpful in improving soil characteristics and hence increasing crop yields. Unfortunately, the sludge contains bacteria, viruses, and parasites should be disinfected prior to any such use. Recent research has shown that sewage sludge can be successfully disinfected by exposure to ionizing radiation. [2].

The ionizing radiation interacts with the pathogenic bacteria both directly and indirectly. Direct interaction takes place with critical molecules like DNA and the proteins present in the microorganisms, thus causing cell death. During indirect interaction, radiolysis products of water (Eq. 1), resulting in formation of highly reactive intermediates that then react with the target bimolecular, culminating in cell death.

$\mathbf{e^-_{eq}}$, H, H_2O. + DNA (microorganism) → Damage to DNA (inactivation of bacteria)

V. RADIATION SOURCES FOR WASTEWATER TREATMENT

High energy radiation sources can be divided into two groups:

a Radioactive Isotopes such as ^{60}C and ^{137}Cs.

b Electron Beam (EB)Accelerators

A. Radioisotope Sources:

The isotope Cobalt-60 (^{60}C) is produced by irradiating the stable isotope of cobalt (^{59}C). The isotope Cesium-137 (^{137}Cs) is separated from spent reactor fuel. Cobalt -60 gives high energy (gamma photons energies are 1.332 MeV and 1.173 MeV). Secium-137 has lower energy (gamma photons having energy of o.662 MeV) but has the advantage of longer half-life.

B. Accelerators for Wastewater Treatment:

Over 1300 electron accelerators are currently in use worldwide for radiation processing and related research [3]. The widespread of this technology is due to the fact that these accelerators, unlike the radioactive isotope gamma sources, can be turned on or off at will and the accelerators can provide relatively higher energy which translates to deeper penetration. Most of those accelerators are used for industrial processing of polymer products such as cables, thermo-shrinking materials, and other applications. However, their use for environmental applications is becoming increasingly important for waste control [3]. A generic structure for an EB treatment facility is shown in Fig. 2. To insure the effectiveness of the EB treatment; the delivery system at the interaction zone should provide for uniform dose distribution as well as delivery of large amounts of wastewater for EB exposure. Three different schemes for wastewater delivery to the interaction zone are shown in Fig. 3, below.

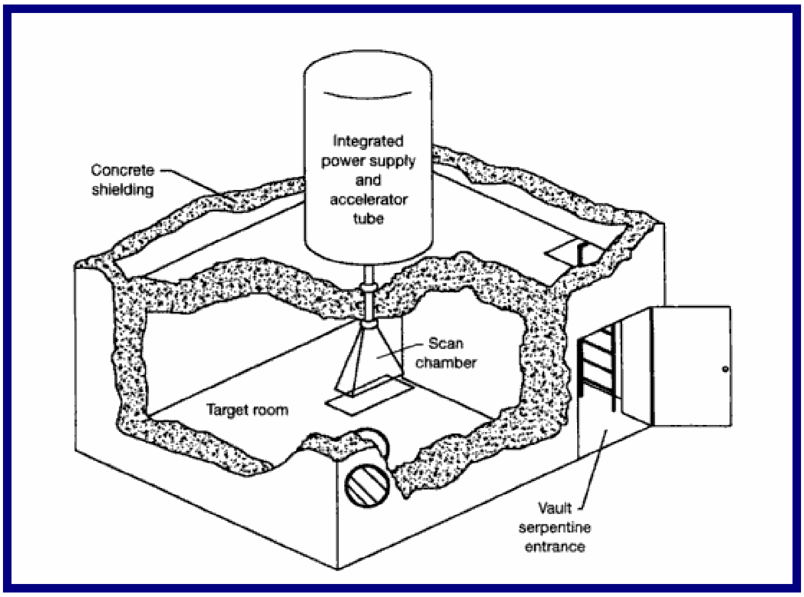


Fig. 2 Schematic for a typical Electron Beam processing Facility.

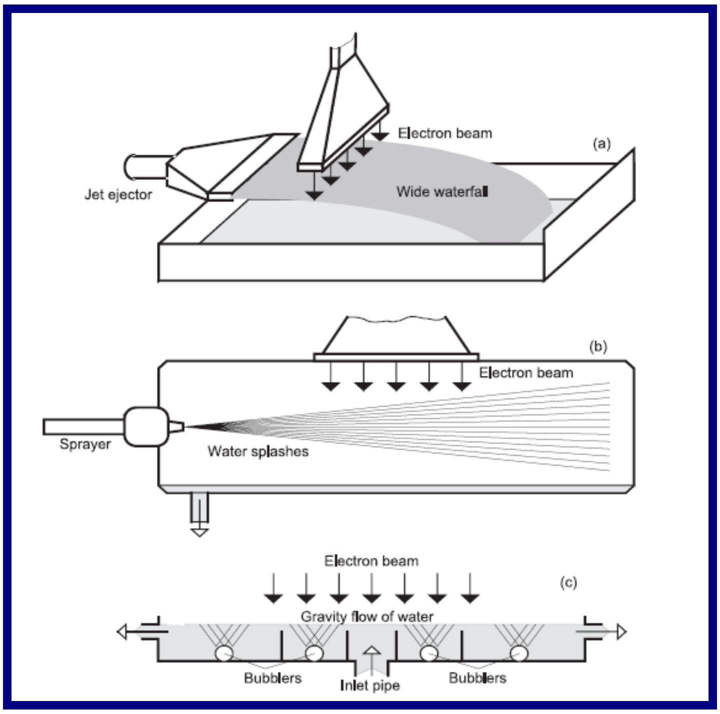


Fig. 3 Different schemes for the interaction zone.

VI. EXAMPLES OF ELECTRON BEAM WASTEWATER TREATMENTS

Application of E B Treatment in the Russian Federation [4]:

The first large scale application of EB was in Russia in the Voronezh synthetic rubber plant. The plant has two purification lines each one uses a 50KW accelerator. The first accelerator was installed in 1984 and the second one was installed in 1988. The EB irradiation results in the conversion of non-biodegradable plant waste into a biodegradable form. Dose required from the accelerator is 300 kGy. This facility treats up to 2000 m^3.

Electron Beam Plant for Wastewater Treatment in Republic of Korea [5]:

In South Korea, an electron beam treatment pilot plant for treating 1,000 m^3/day of dyeing wastewater was constructed in Daegu and has been in operation since 1998. It utilizes an accelerator having the energy of 1MeV and producing beam power of 40 kW. The system is shown schematically in Fig. 4. For the uniform irradiation of water, nozzle type injector with the width of 1.5 m is used. The wastewater is injected under the E-beam irradiation area through the injector to obtain the adequate penetration depth. The speed of injection can be varied to achieve certain dose. This plant is combined with a biological treatment system. It demonstrated the reduction of chemical reagent consumption, and also the reduction in retention time with the increase in removal efficiencies of up to 30~40 times.

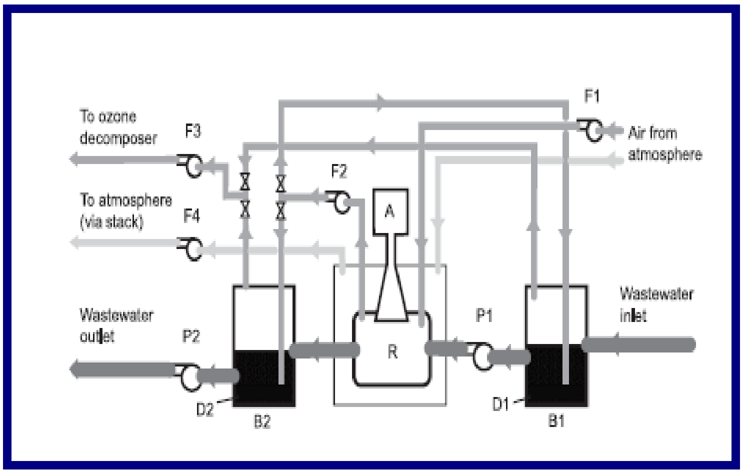


Fig. 4 Schematic of the pilot water treatment plant in Daegu, Republic of Korea, [5].

Example of Research in the United Sates [6]:

In the United States, one of the examples demonstrating the effectiveness of the use of electron beam in treating groundwater contaminated with volatile organic compound (VOC) was the research done by the High Voltage Environmental Applications, Inc. (HVEA) and demonstrated in 1994, [6]. This research aiming at developing E-beam technology was funded by the Superfund Innovative Technology Evaluation (SITE) program established by the U.S. Environmental Protection Agency. The E-beam was contained in an 8- by 48-foot trailer (2.44m by 14.64m). The E-beam system treated about 70,000 gallons of groundwater contaminated with VOCs at a maximum flow rate of 50 gallons per minute (gpm). For the run with the best overall performance, the removal efficiencies (RE) observed for trichloroethylene (TCE) and tetrachloroethene (PCE) were 98% and 99%, respectively.

Removal of Organic and Petrochemical Pollutants in Brazil [7]:

Researchers in Brazil have performed studies to predict how the electron beam treatment of industrial effluents can be considered a practical technology in removing organic contaminants in water treatment plants. One of their studies [7] compared the use of electron beam processing with activated carbon adsorption to clean up a real industrial effluent. The electron beam treatment was performed using an electron beam accelerator from Radiation Dynamics Inc. Brazilian researchers also compared the results of treating water polluted with three petrochemical pollutants with electron beam dose of 50 KGy with those processed by a convention treatment using activated carbon. They concluded from the results that the EB process shows organic removal efficiency similar to that of the more conventional treatment using the activated carbon process if adequate irradiation dose was delivered to the organic pollutant.

VII. CONCLUSION

Radiation treatment technology represents a viable solution to the problem of waste water treatment. Several countries have already taken the initiative of implementing electron beam in the irradiation of wastewater. It is expected that the spread of use of this technology will provide the impetus for the accelerator industry to produce linacs specially designed for this application. It is hoped that the increase in number of units produced would help the cost of such technology to decline to a level that makes it affordable and economically attractive to many countries.

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